10.1: MASERS AND MILLIMETER WAVES

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This paper examines the characteristics of several types of proposed masers to see what characteristics they can be expected to have in the region between one and a tenth millimeter. In particular, extimates are given for the maximum power output and efficiency of a number of maser systems operating as oscillators or power sources. Additionally, the expected noise temperature for maser systems in this frequency region are compared with those at lower frequencies.

Table I lists a table of energies for a photon and the number of photons required per second to obtain a power output of one watt. It is to be noted that the minimum number of radiating systems to produce a watt of power at one millimeter is approximately a thousand times that at optical frequencies, so that we must expect to deal with either greater numbers of radiating particles or higher speed pumps to get the same power output.

The three most common schemes for obtaining the inverted population for maser operation are pumping with higher frequency radiation, electron bombardment, and the special separation of a beam of molecules with different energy levels with a large inhomogeneous field. Both the first and last of these three schemes seem to limit the maser output power to a few milliwatts or less.

It is shown that for a molecular beam maser to oscillate we need to supply an excess of high energy molecules at a rate of about 10^{13} molecules per second. As only 2 or 3 per cent of the molecules are in the energy states of interest and the best focusing systems are 10 to 20 per cent efficient, this corresponds to a gas flow rate of about 10^{16} molecules per second.

At a background pressure of 10^{-5} mm of Hg and a pumping speed of 10^4 liters per second we are limited to a gas flow of about 4×10^{18} molecules per second or a power output of about one microwatt at one millimeter.

A power source of this size will not solve the source problem for submillimeter waves but it may prove very useful as a frequency standard and a narrow band low noise amplifier. Table II lists a number of molecules which are currently being considered for use in beam masers in this region.

The radiation pumped maser is handicapped by the lack of available power sources with frequencies only slightly larger than the desired transition frequencies. At present the best vacuum tubes generate less than 150 mw at wave lengths less than about 3 mm and to my knowledge there are no tubes putting out an appreciable amount of power at less than 1 mm. Black body radiators are both weak and inefficient in the region between one and a tenth millimeter. Although strong optical sources are available both from lasers and gas discharge tubes, these sources are inefficient. The maximum efficiency for an optically pumped system is given by ratio of the frequencies and this at 1 mm is on the order of a tenth of a per cent. In order to invert the populations it is desirable to have hf large compared to KT. However, at room temperature KT is twenty times hf at 1 mm and at $3^{o}K$ it is only 1/5 hf. Thus, just as with the microwave solid state masers, it will be most convenient to work at low temperatures. Although it may be possible to dissipate a hundred watts with a liquid helium or a liquid nitrogen system and to get a tenth of a watt of maser power, a watt of input power and less than a milliwatt of maser power is much more likely. The highest output power to my knowledge for a solid state system of this kind is 70 μw out for .5 w at 33 Gc/s, pulsed[1]. Energy level schemes which may be useful for solid state maser in the submillimeter wave region include cyclotron resonance, or Landau levels, and impurity band levels in semi-conductors.

A third approach to the generation of millimeter and submillimeter waves is to use either photo emissions or photoconductive devices as a mixer for two optical maser signals. A photo cathode has been shown to provide a substantial current which is density modulated at the difference frequency between the two optical maser signals. The extraction of power from this density modulated beam is subject to the same circuit problems which have been faced by people trying to design other vacuum tubes for this region; however, it appears likely to provide a convenient source for a bunched beam. A point contact diode illuminate with two optical maser signals provides another simple source for small amounts of power. Some characteristics of these devices will be discussed in detail.

TABLE I

Wave Length	Frequency	Energy of a Photon hf joules	ev	Minimum # of Photons per second for 1 watt of power
1 mm	3×10^{11} cps	1.98×10^{-22}	1.24×10^{-3}	5×10^{21}
.1 mm	3×10^{12} cps	1.98×10^{-21}	1.24×10^{-2}	5×10^{20}
6.9×10^{-4} mm	4.35×10^{14} cps	2.87×10^{-19}	1.8	3.5×10^{18}
10 mm	3×10^{10} cps	1.98×10^{-23}	1.24×10^{-4}	5×10^{22}

TABLE II

Possible Molecules For Beam Masers

Molecule	Transition	Wave Length	Estimated Minimum Starting Current (molecules/sec.)
HCN*	$J = 1 \leftrightarrow 0$	3.4 mm	3.3×10^{12}
NH_3*	$J = 2 \leftrightarrow 1$	.252 mm	1.5×10^{13}
CH_3F +	$J = 2 \leftrightarrow 1$	2.95 mm	1.7×10^{13}
CH_3CN+	$J = 5 \leftrightarrow 6$	2.72 mm	3.3×10^{12}
CH_3NC+	$J = 4 \leftrightarrow 5$	3. mm	3.2×10^{12}
ND_3**	$J = 2 \leftrightarrow 1$	.485 mm	4×10^{13}

*F. S. Barnes, Quantum Electronics, Columbia University Press (1960) Edited by Townes.

+J. B. Newman, Advances in Quantum Electronics, Columbia University Press (1961).

**V. E. Derr, J. J. Gallagher, M. Lichtenstein, Proceedings of 15th Annual Symposium on Frequency Control.

1. J. S. Thorp, "Two-level Maser Amplification at 8 mm Wavelengths," Advances in Quantum Electronics, Columbia University Press, 1961, pp. 602-09.